Webinar #6- Physical Science
Part 2: Fluid Dynamics

UNOOSA Hypergravity/Microgravity Webinar
May 26, 2021

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Outline

1. **How does fluid behave in microgravity?**
2. **Liquid in container**
   → Propellant tank for spacecraft
3. **Flow boiling and two-phase flow**
   → Thermal management system for space station and spacecraft
4. **Marangoni convection**
   → Material processing
5. Concluding remarks

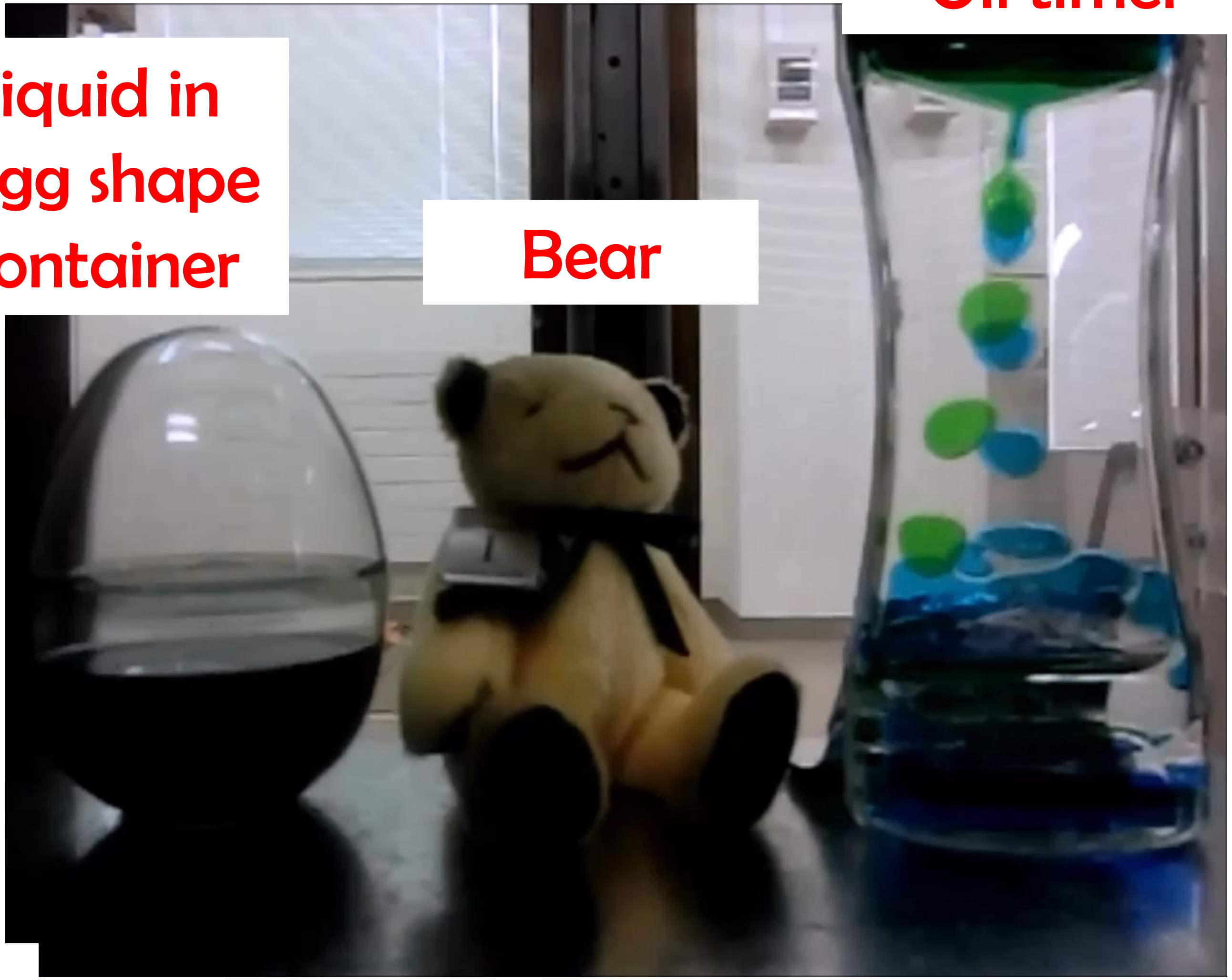
1. How does fluid behave in microgravity?

Simple experiment by drop capsule

2m

Acceleration area

Capsule

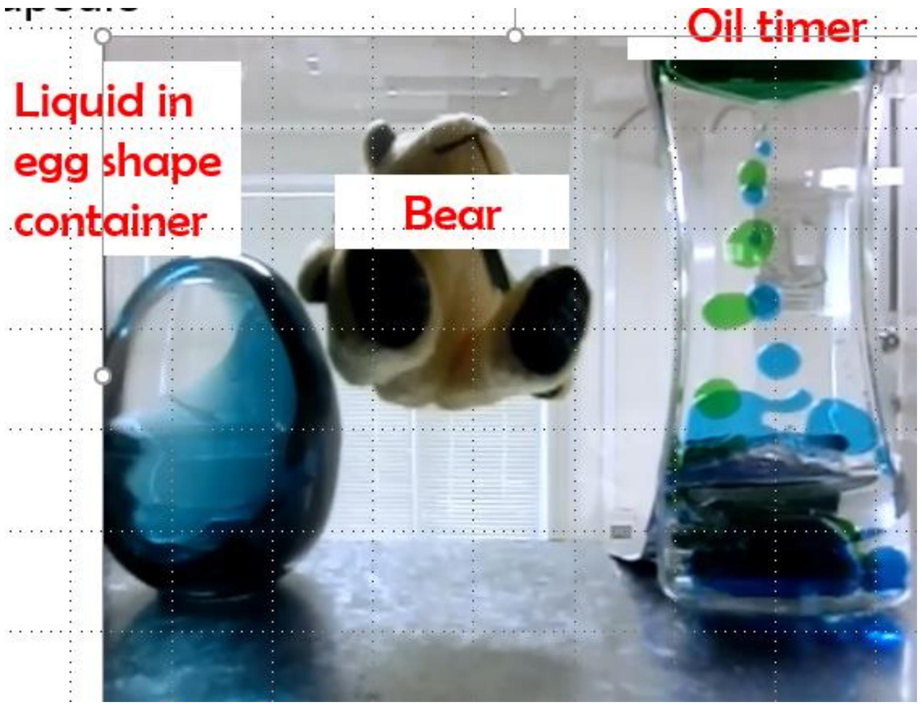


In the capsule

1. How does fluid behave in microgravity?

What can we find in this experiment?

- Bear floats. → Weightlessness
- Liquid in the container becomes round.
  → Surface tension
- Liquid in the container climbs the wall.
  → Surface tension, wetting
- Droplet doesn’t drop, stays.
  → Weightlessness
- Droplet gradually becomes round.
  → Surface tension

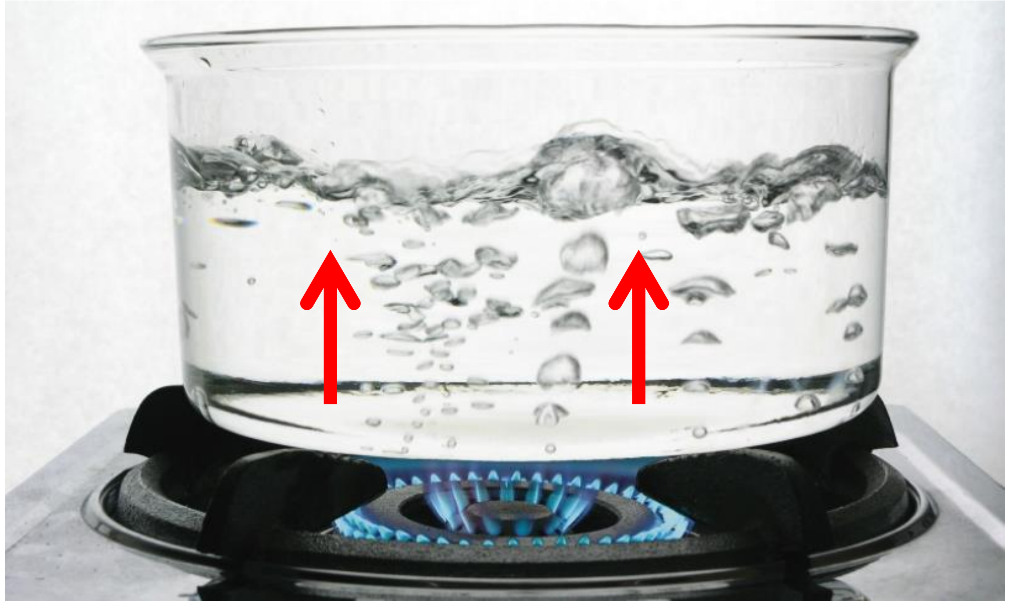


1. How does fluid behave in microgravity?

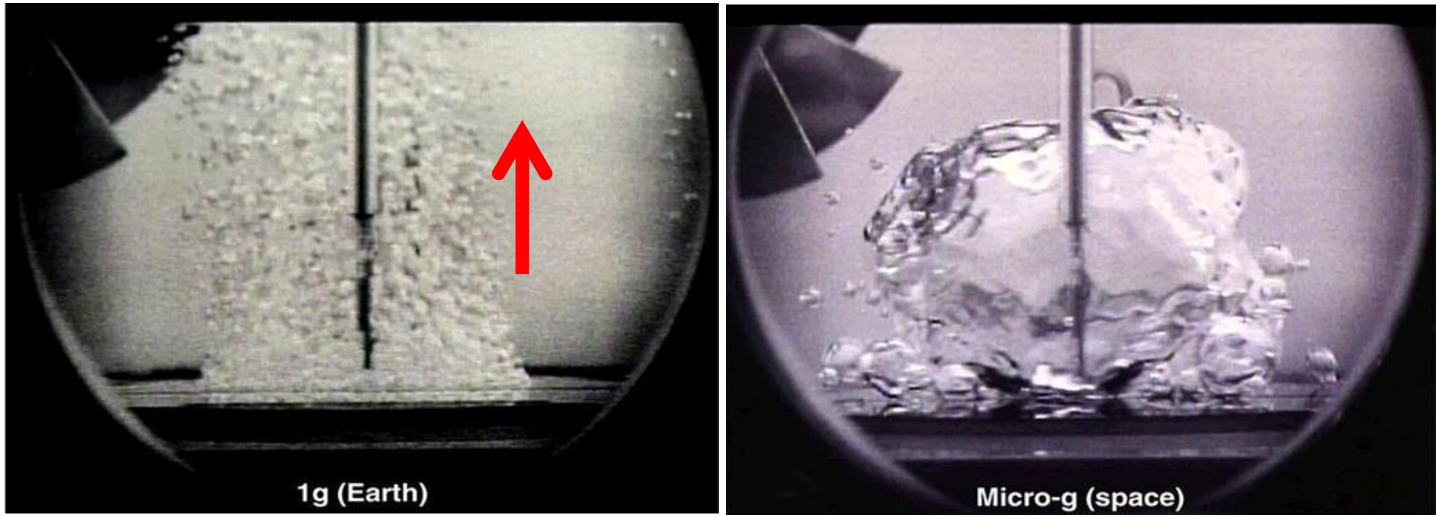
- Droplet doesn't drop, stays.

  How about bubble?

- Bubble doesn't rise, and stays also.



Boiling bubble

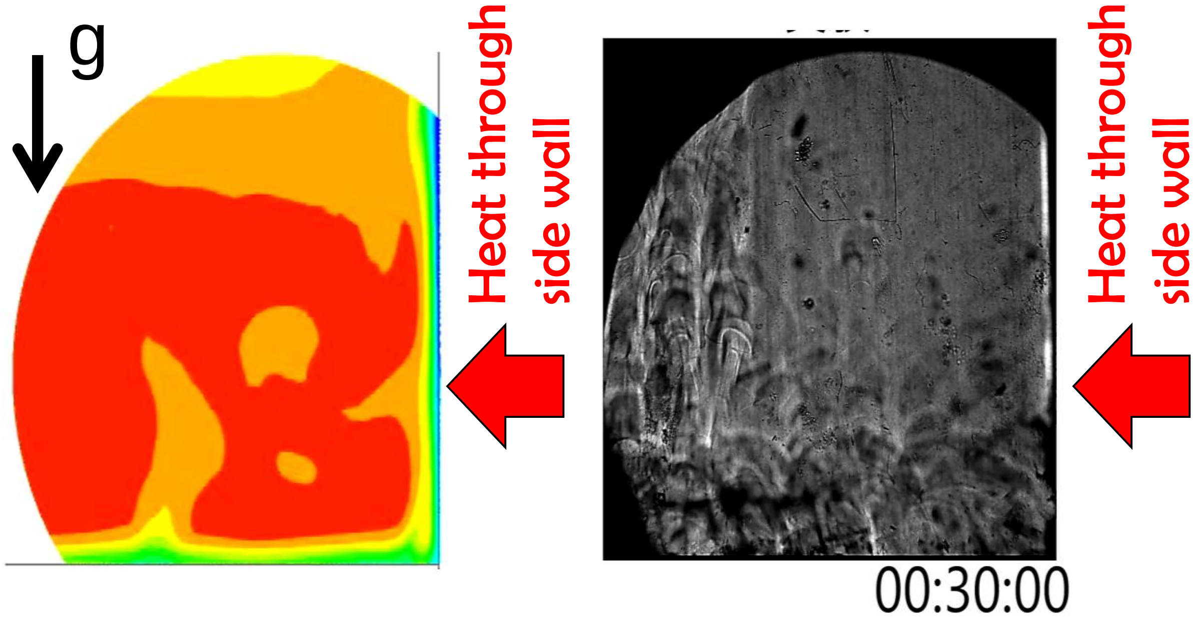


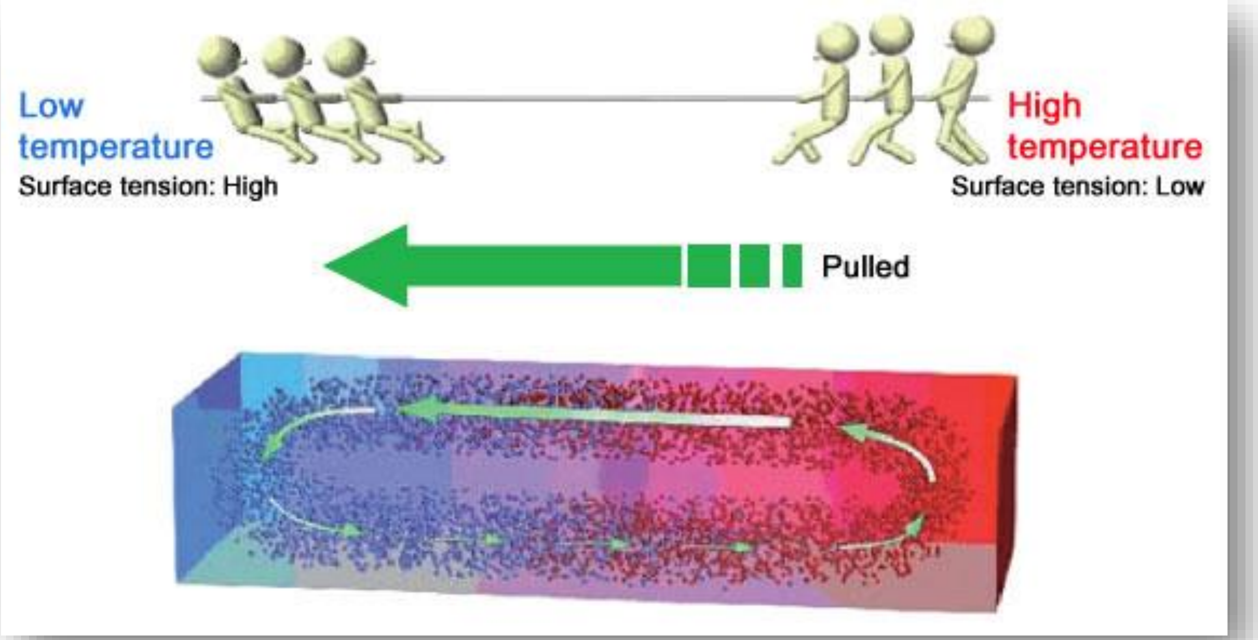
https://www.nasa.gov/image-feature/pool-boiling-1g-vs-microgravity

Boiling bubble in microgravity (right)

1. How does fluid behave in microgravity?

How about natural convection?





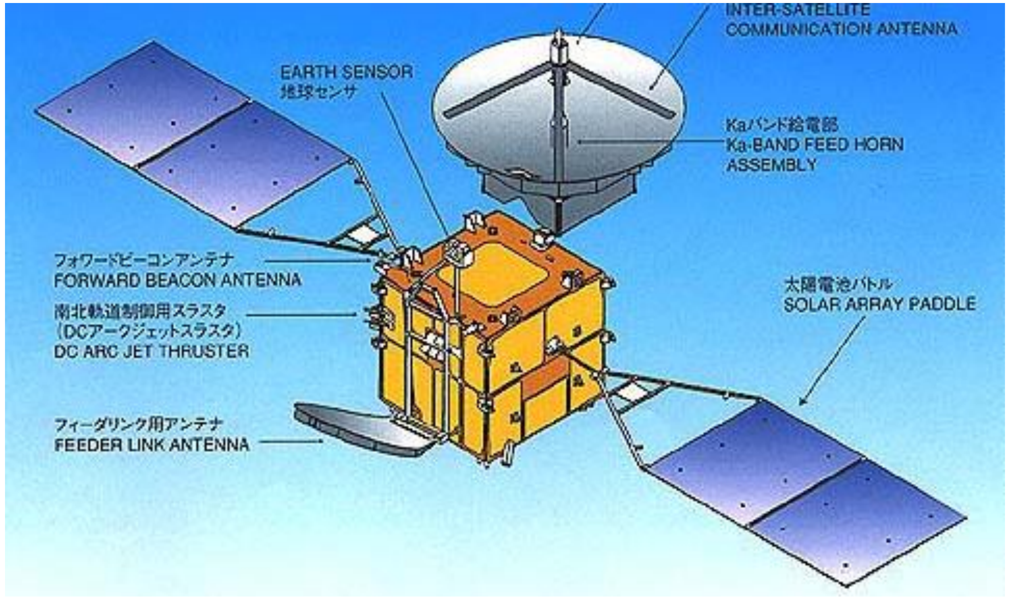
https://iss.jaxa.jp/en/kiboexp/theme/first/marangoni/

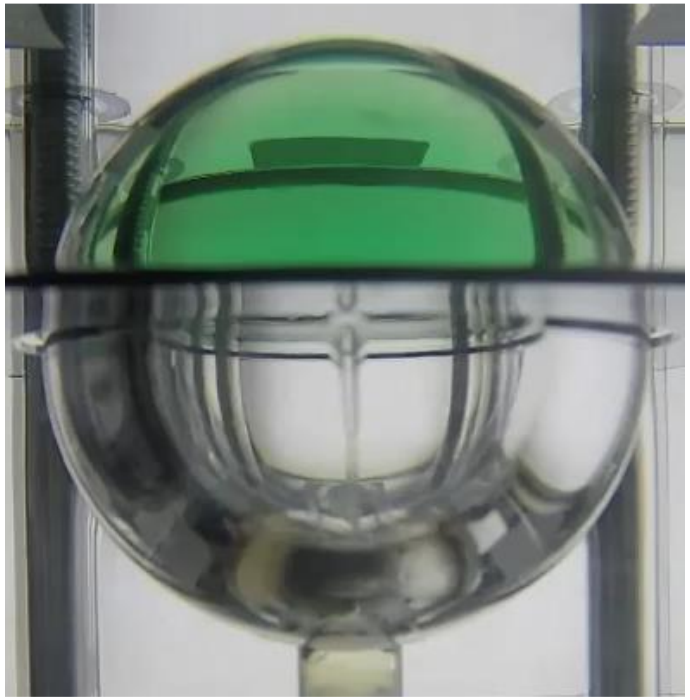
<u>Natural convection in 1G</u>
Convection due to buoyancy

<u>Marangoni convection</u>
Convection due to difference of surface tension

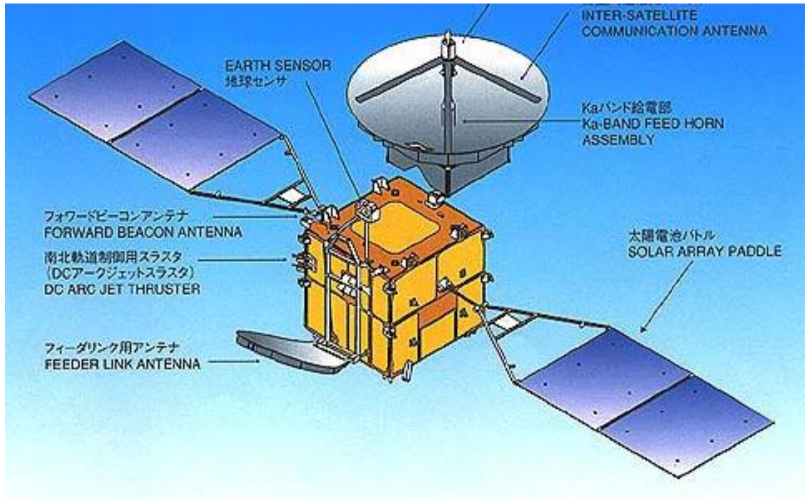
2. Liquid in the container

→ Propellant tank for spacecraft

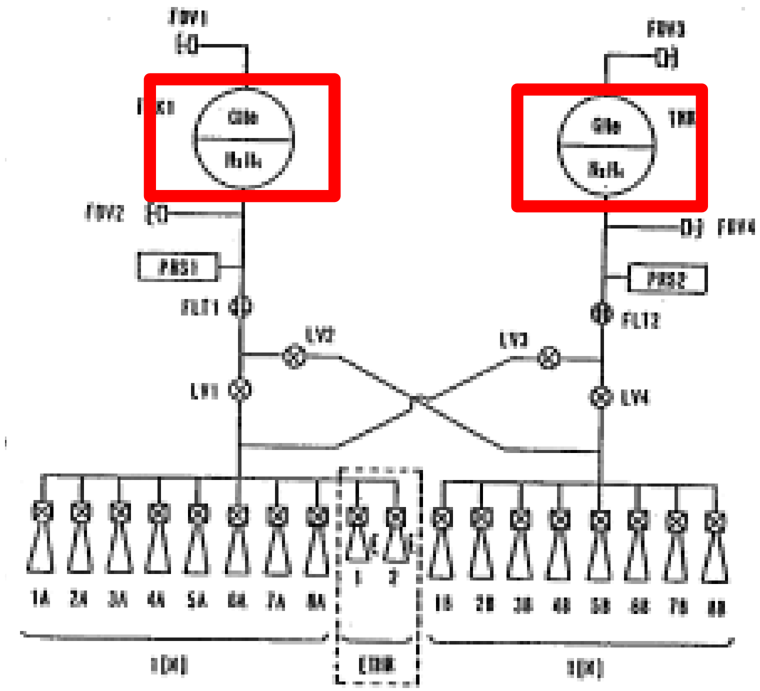


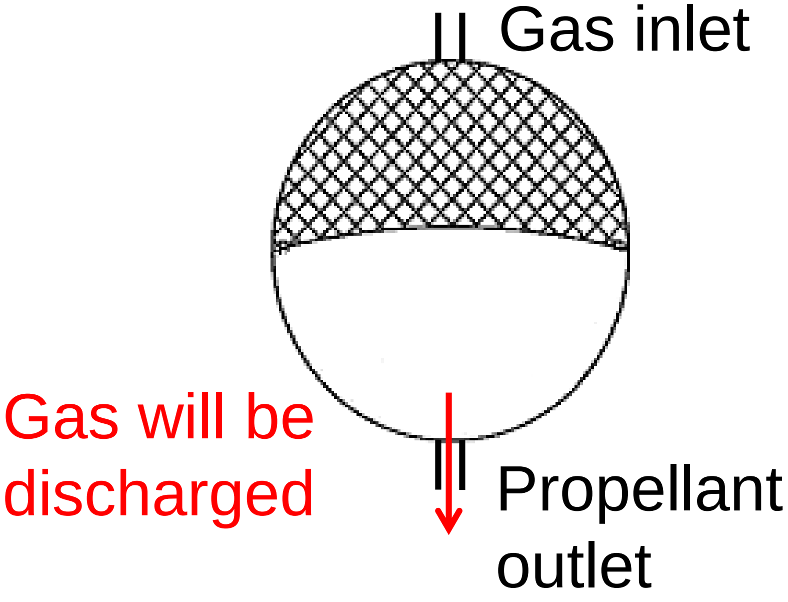


Propellant tank for artificial satellite and spacecraft

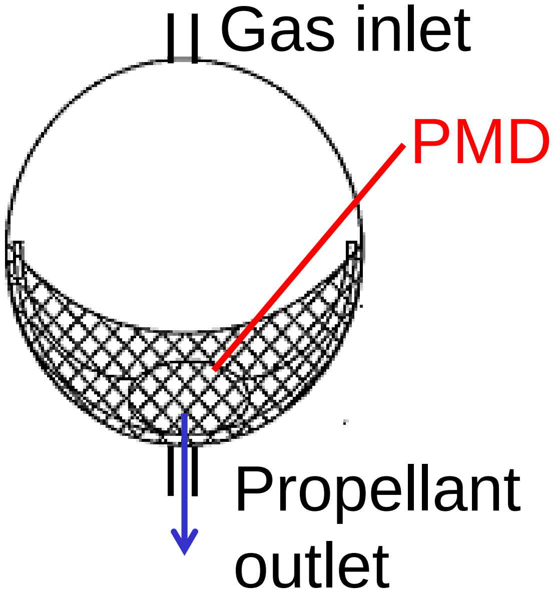


http://www.pmdtechnology.com/PMD%20Photos.html



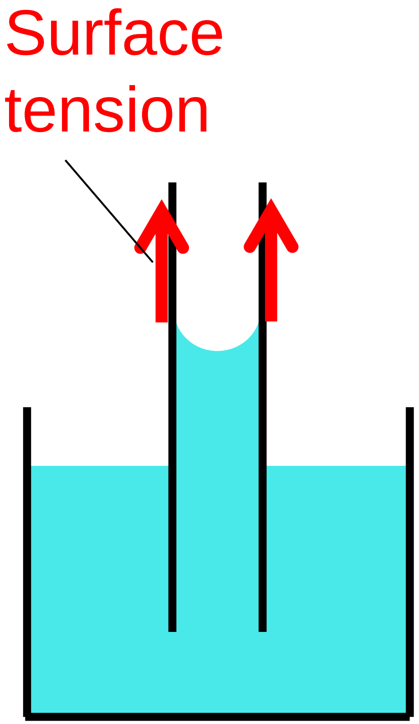


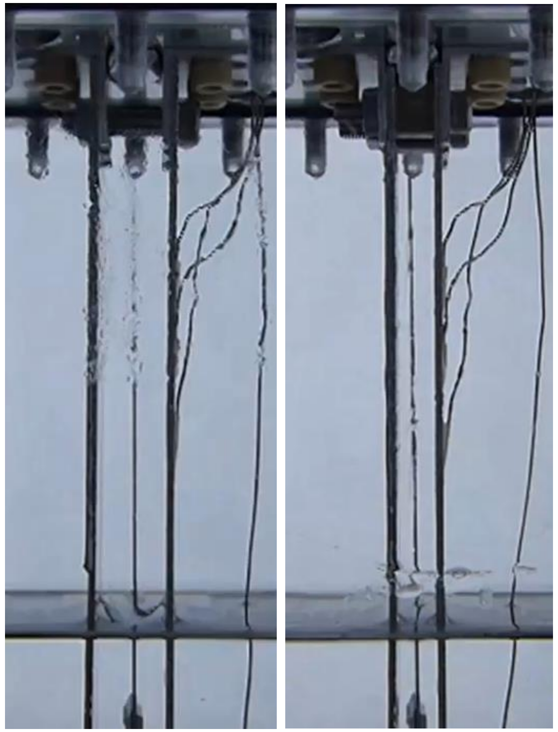
w/o PMD



With PMD

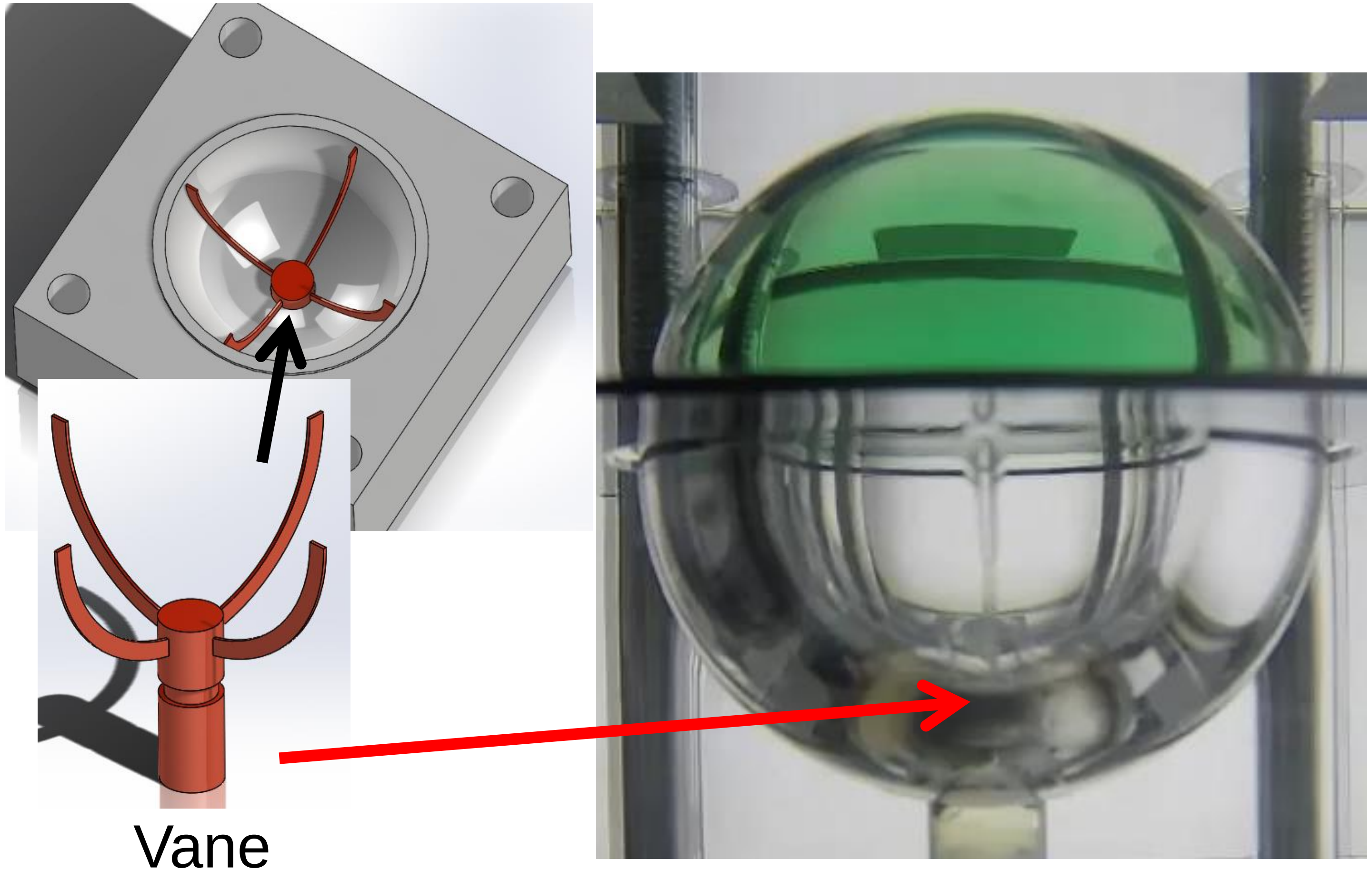
→Propellant tank for artificial satellite and spacecraft





- Liquid rises higher in narrower gas.

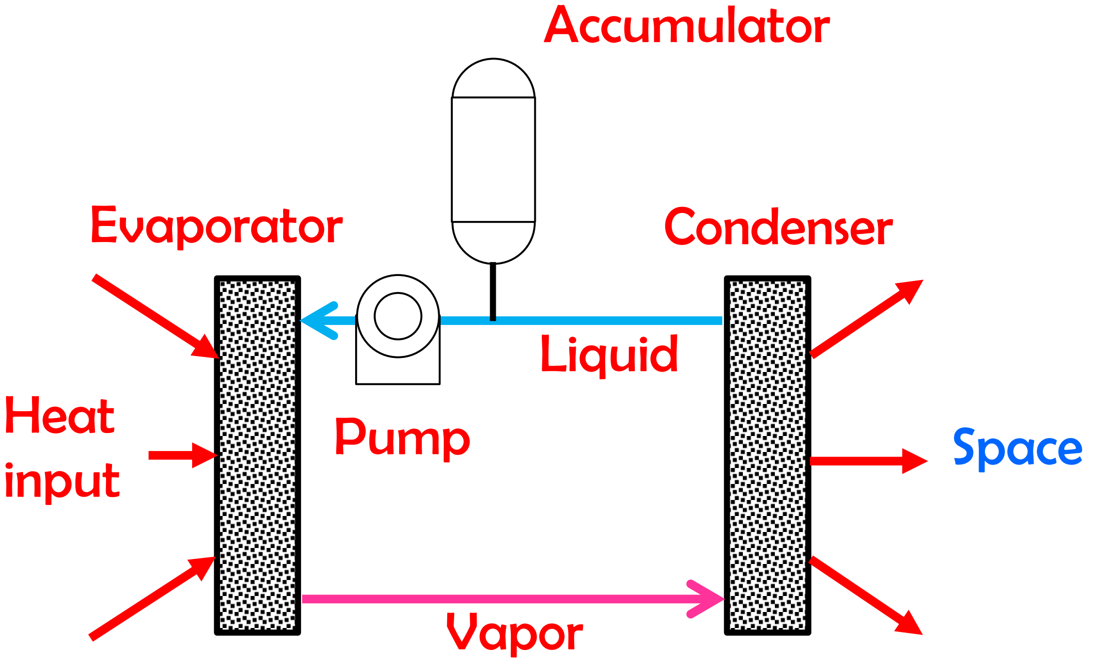
Liquid tends to gather in narrower space.



- Narrow space is formed on the outlet.
- Propellant will be trapped on the outlet.

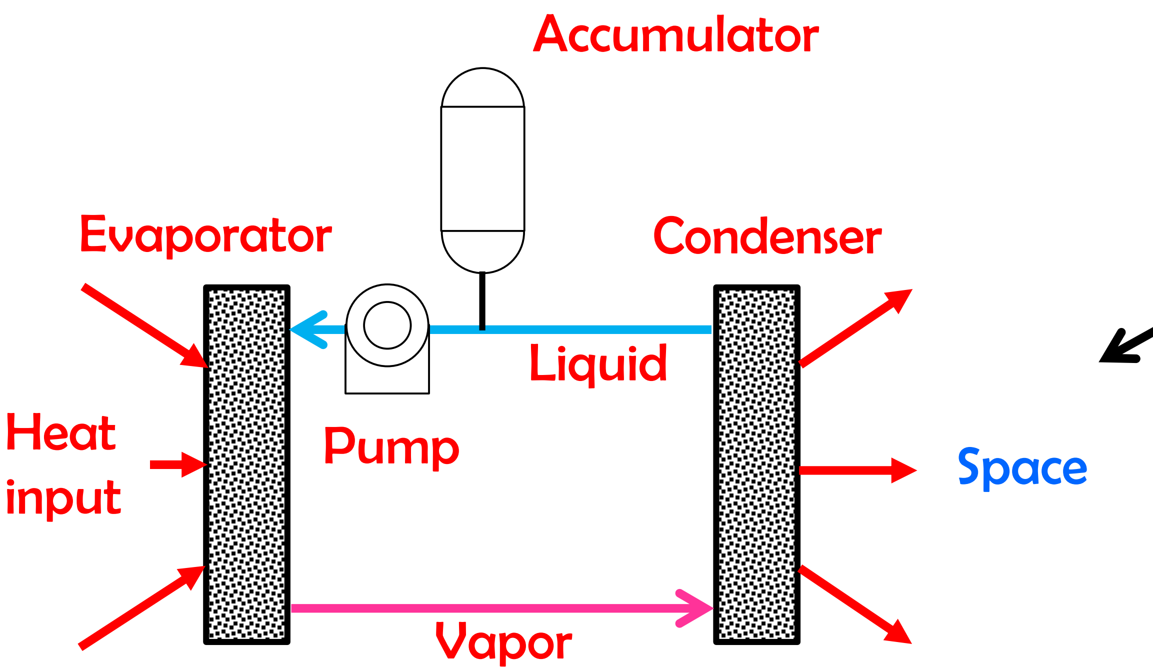
3. Flow boiling and two-phase flow

→ Thermal management system for space station and spacecraft

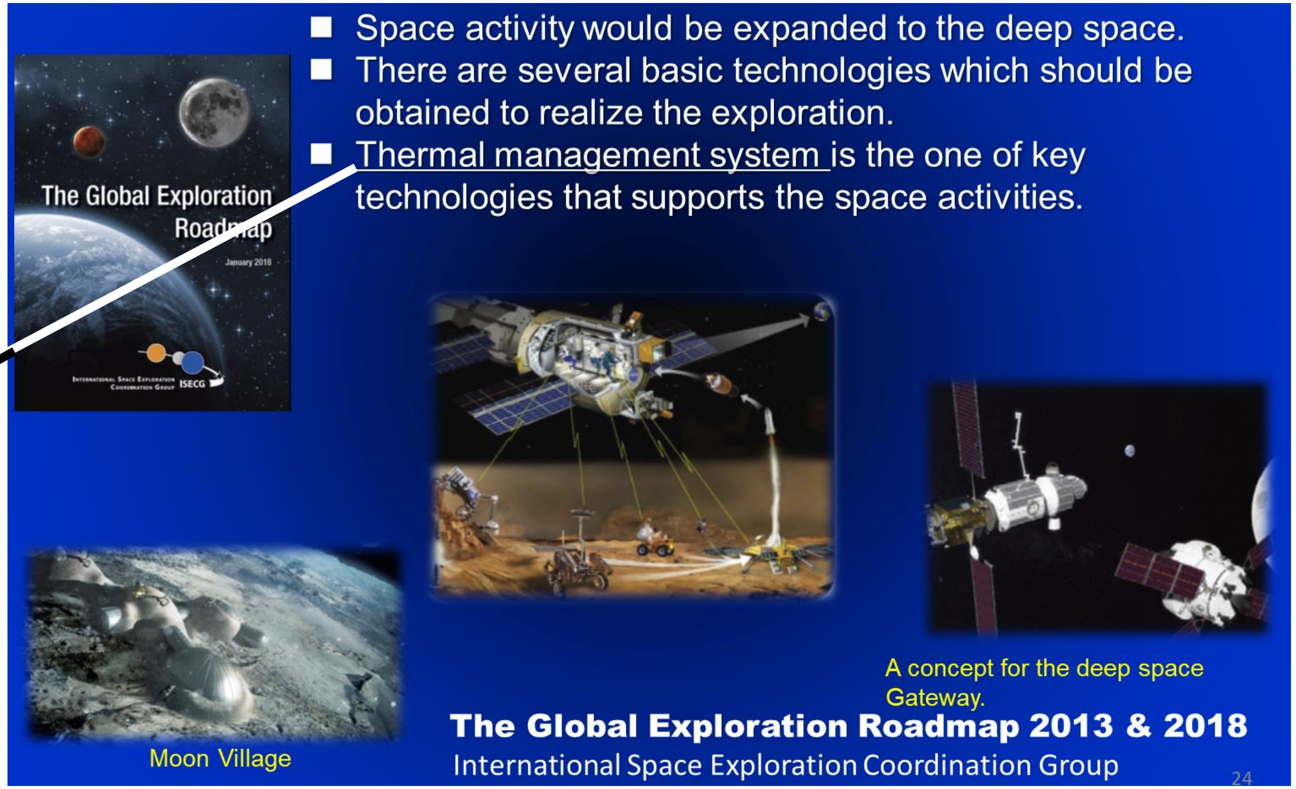


Two phase thermal management system

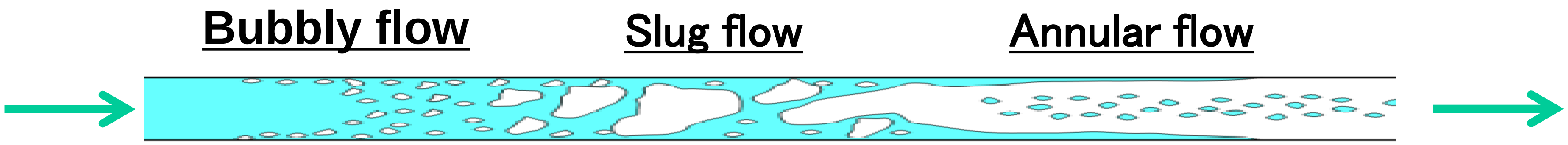
Boiling two phase flow



Two phase thermal management system



Boiling two phase flow
liquid and vapor

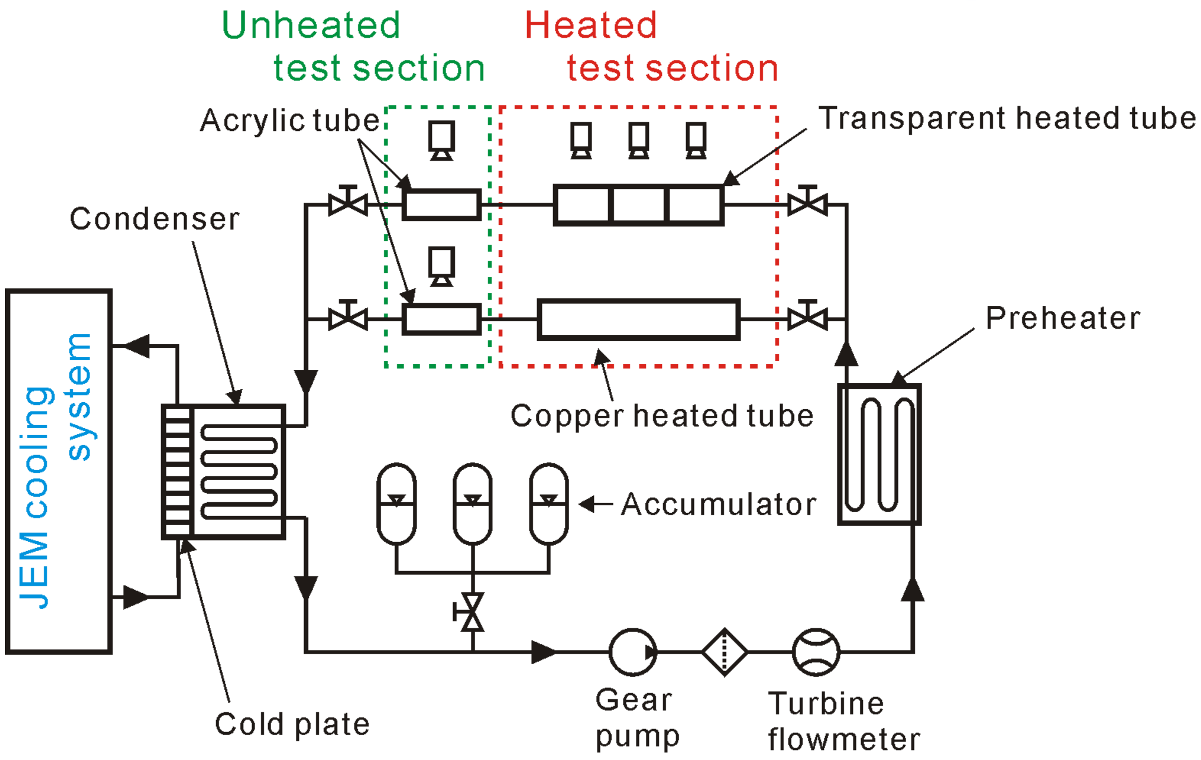


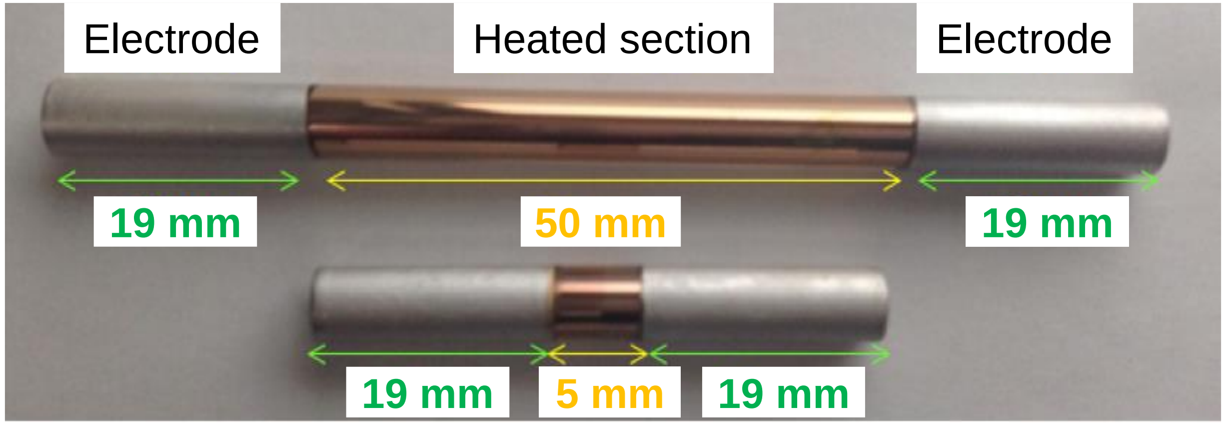
Thermal characteristics of boiling two phase flow depends on the structure of free surface.

Two-Phase Flow Experiment in ISS
TPF Two Phase Flow

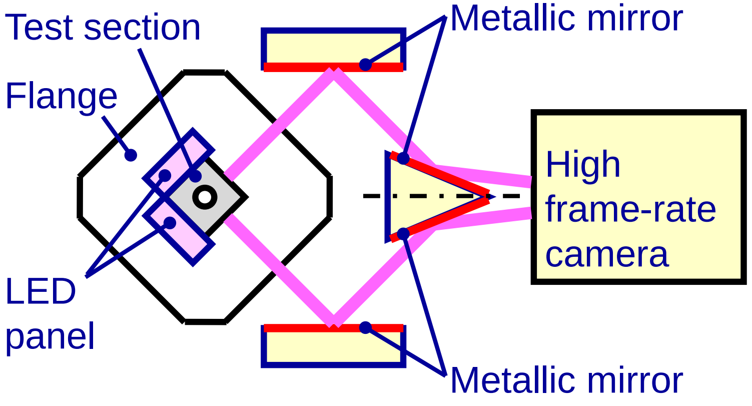
Kyushu Univ., Kobe Univ., Univ. of Hyogo, Tokyo University of Science, The Univ. of Kitakyushu, Muroran Institute of Technology, JAXA, IHI Aerospace, JAMSS, JSF.

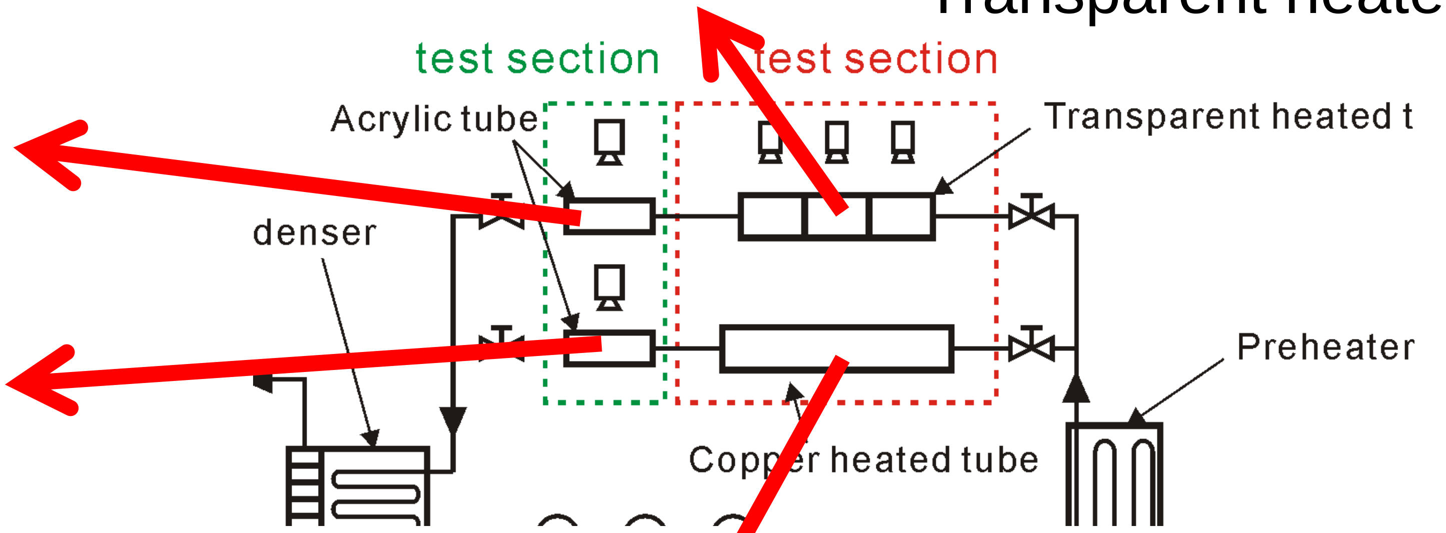
TPF-1 July,2017 - May,2018   TPF-2 February, 2019 – July, 2019

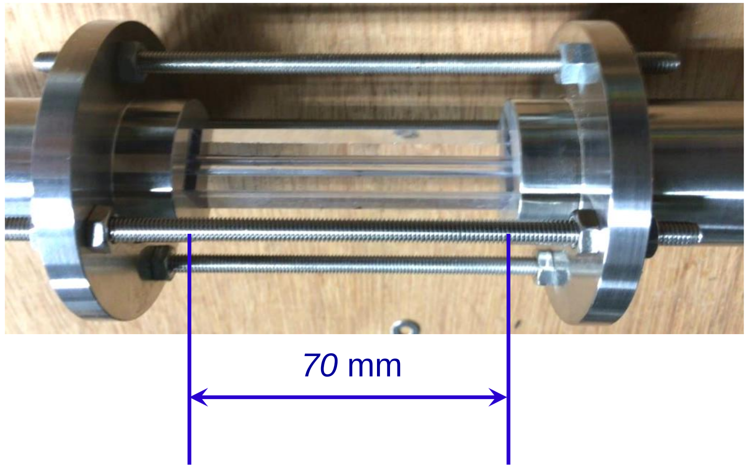




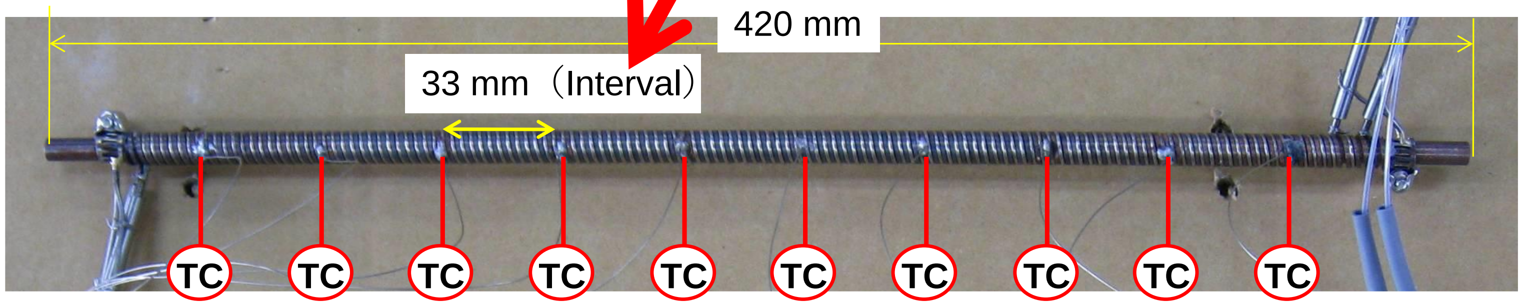
Transparent heated tube





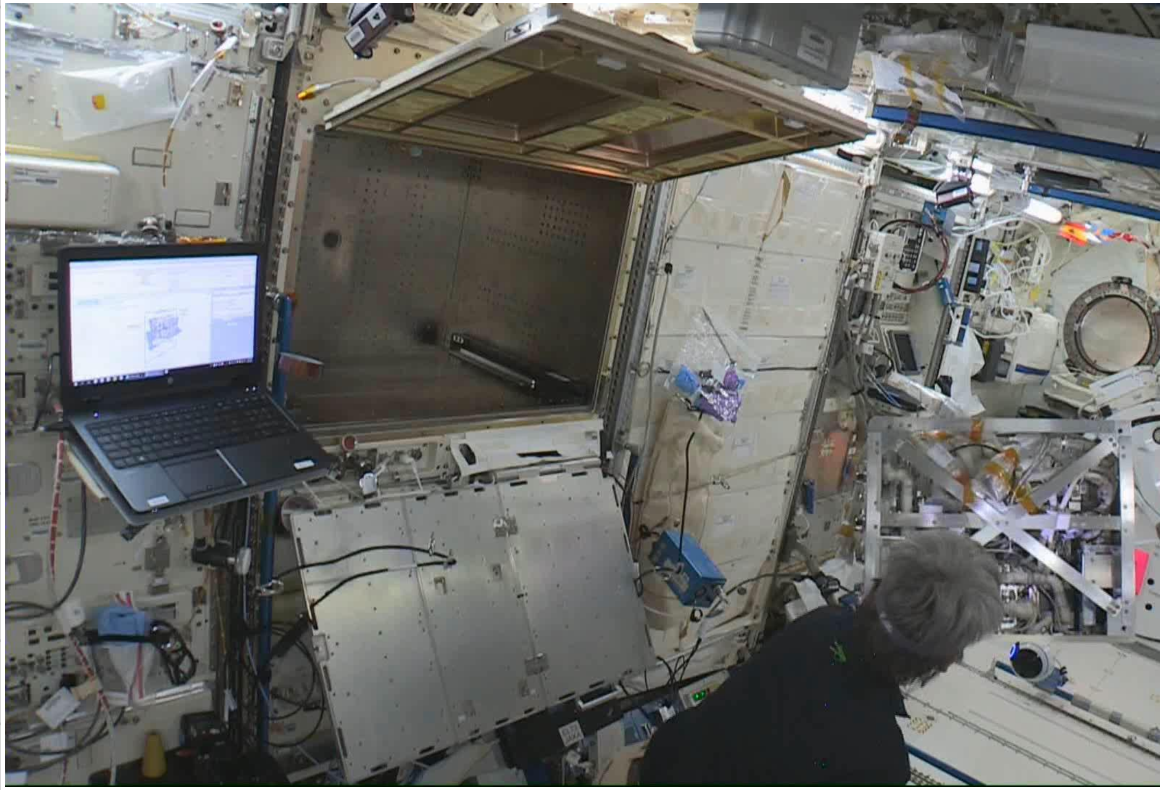


Unheated test section



Copper heated tube

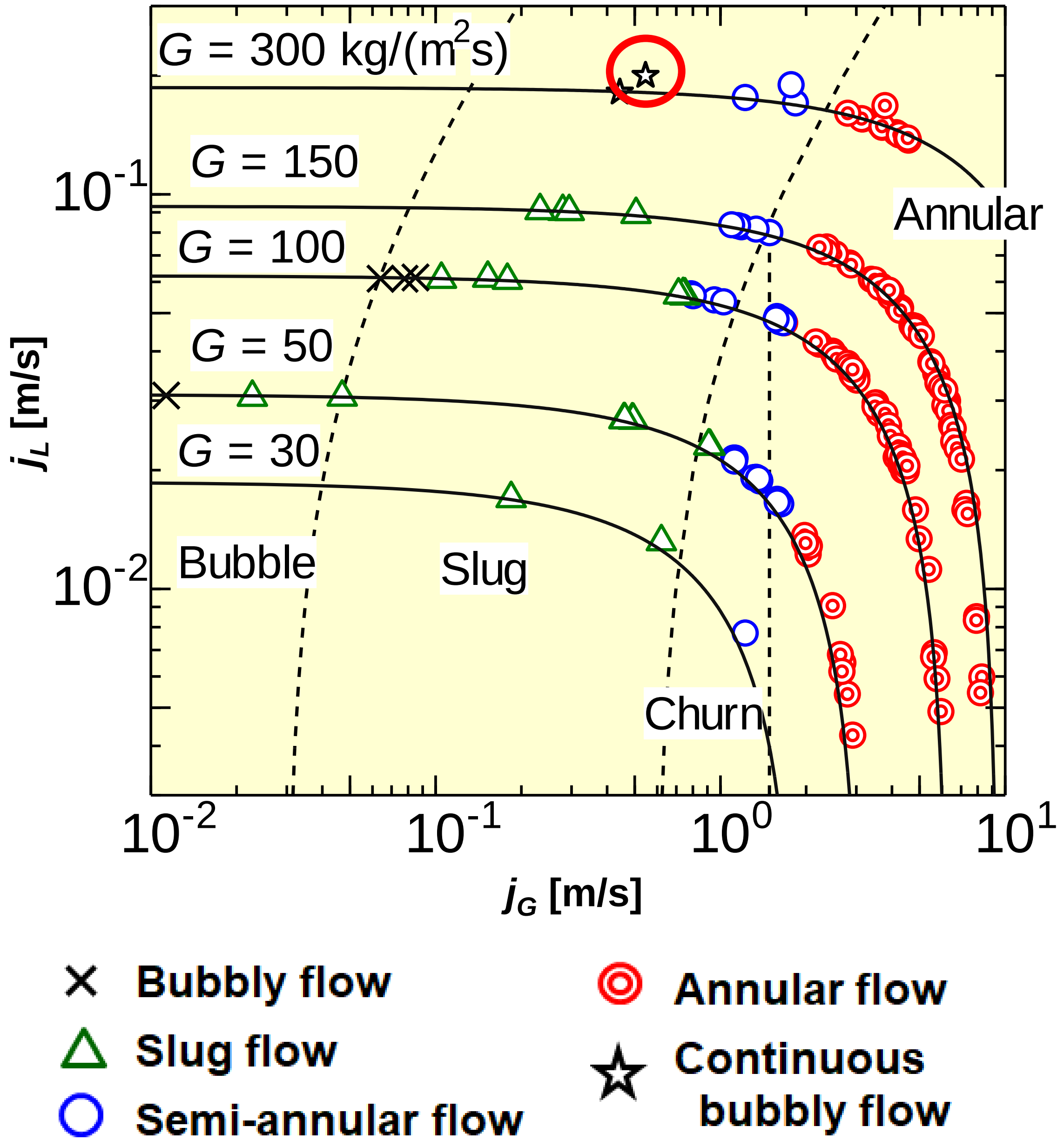
Power supply to heaters	300 W
Test fluid	n-perfluorohexane
Inner diameter of test tubes	d_i = 4 mm
Heated length	l = 50 mm×2+5 mm×1 for transparent heated tube l = 368 mm for metal heated tube
Pressure (observation section)	P = 105 – 125 kPa
Mass flux	G = 30-300 kg/(m^{2}s)
Liquid subcooling at inlet of heated test section	ΔT_{sub} = 0-10 K
Vapor quality at outlet of heated test section	x = 0 – 0.71
Heat flux	q = 0 – 28.3 kW/m^2

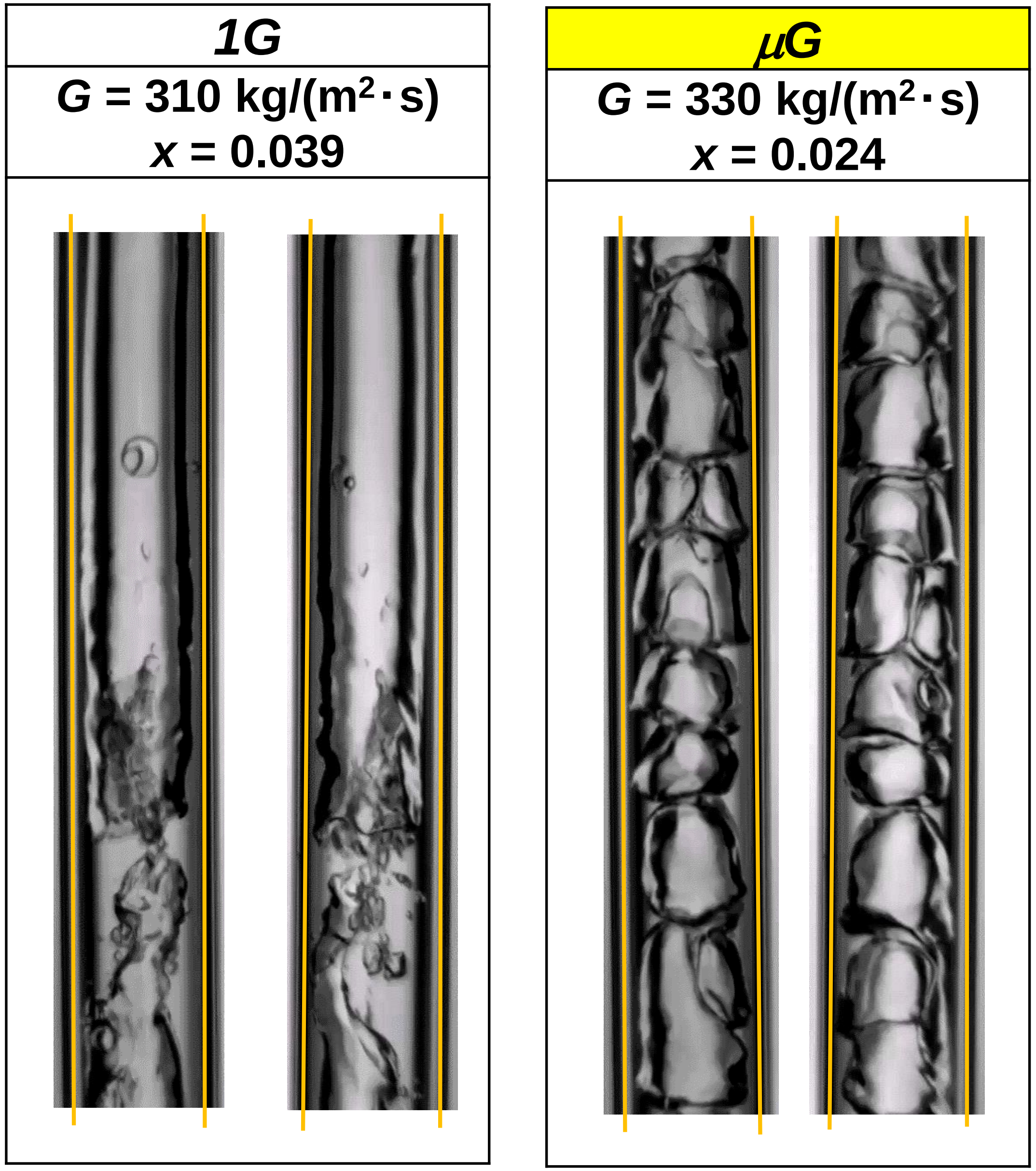


Size : W 800mm × D 650mm × H 500mm

Mass: 140 kg

Flow pattern map



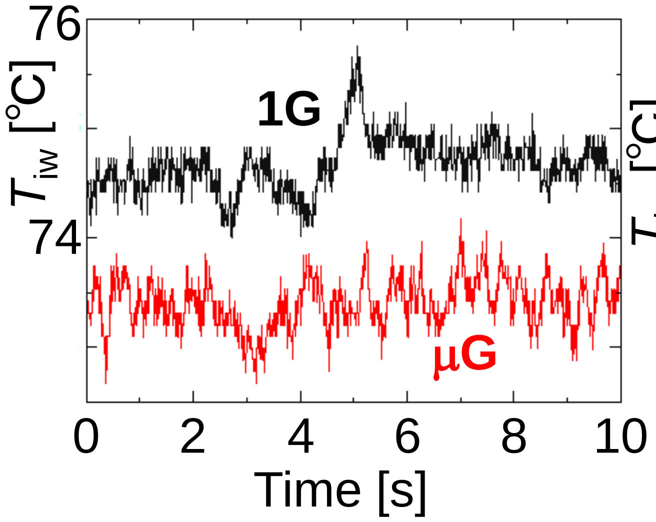


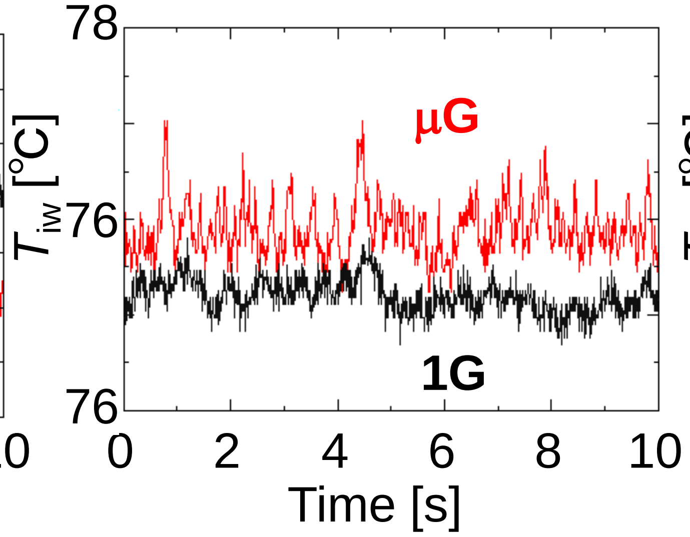
Continuous Bubble Flow

Boiling behaviors in the glass heating tube (G=100 kg/(m²s))

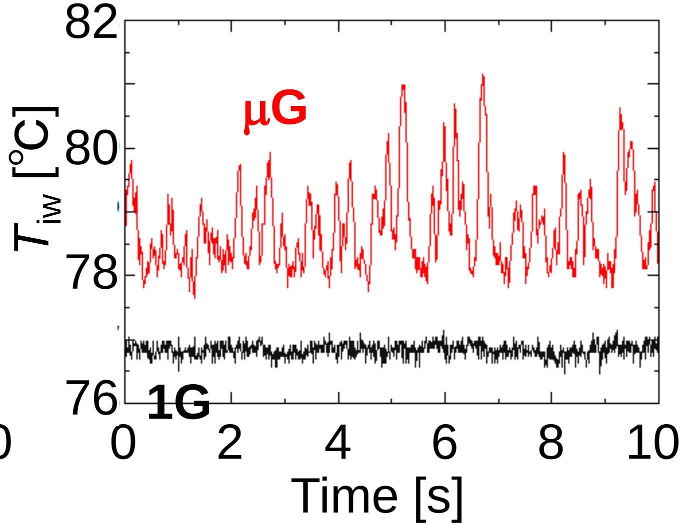
Higher heat transfer coefficient ↓

Low heat flux



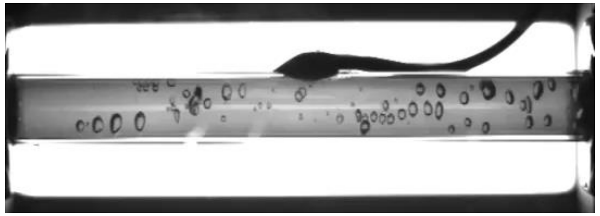


High heat flux

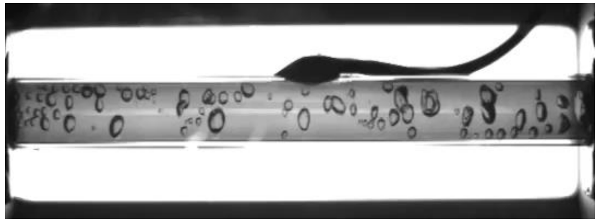


1G (vertically upward)

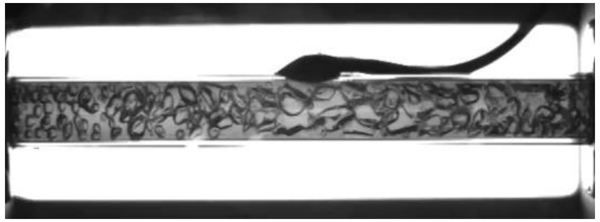
q = 14.5 W/m²



q = 18.6 W/m²

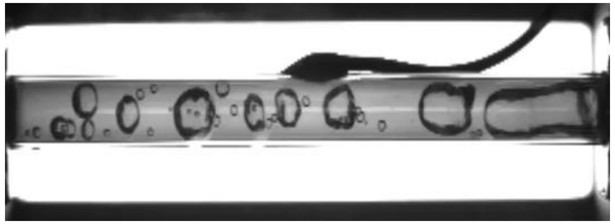


q = 26.9 W/m²

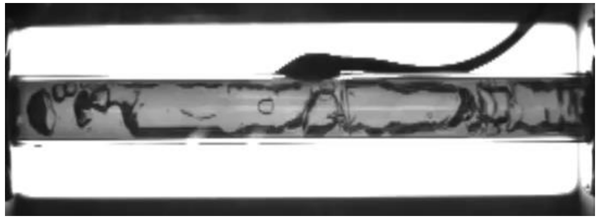


μG

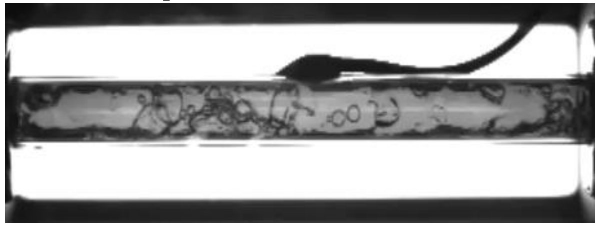
q = 14.1 W/m²



q = 20.0 W/m²

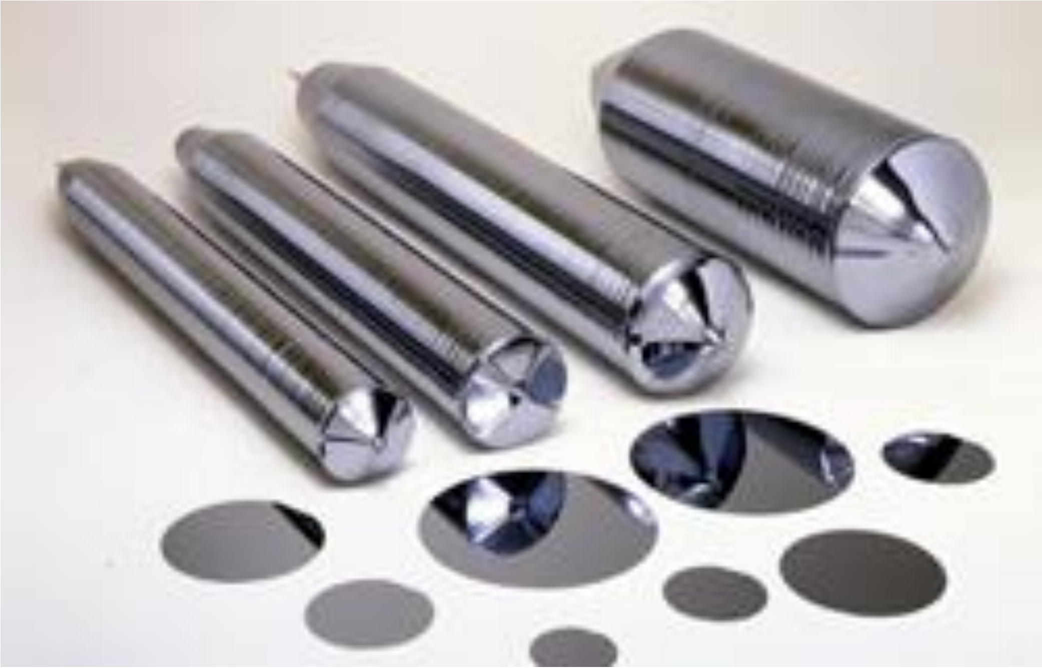


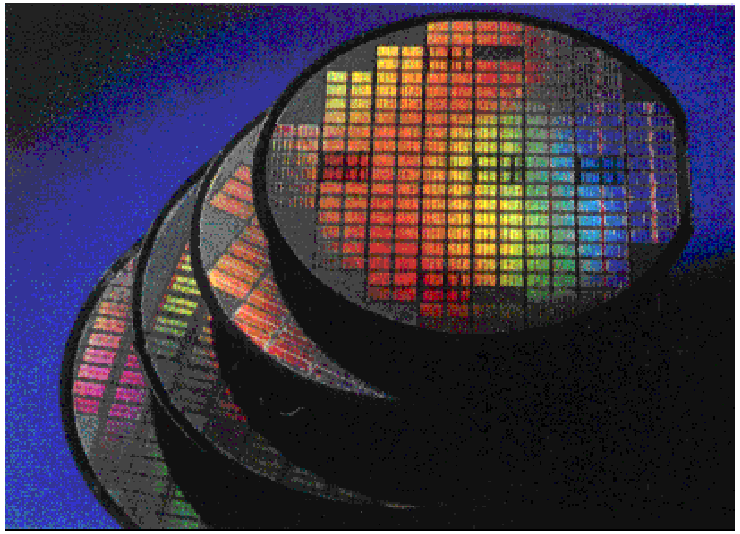
q = 28.3 W/m²



4. Marangoni convection

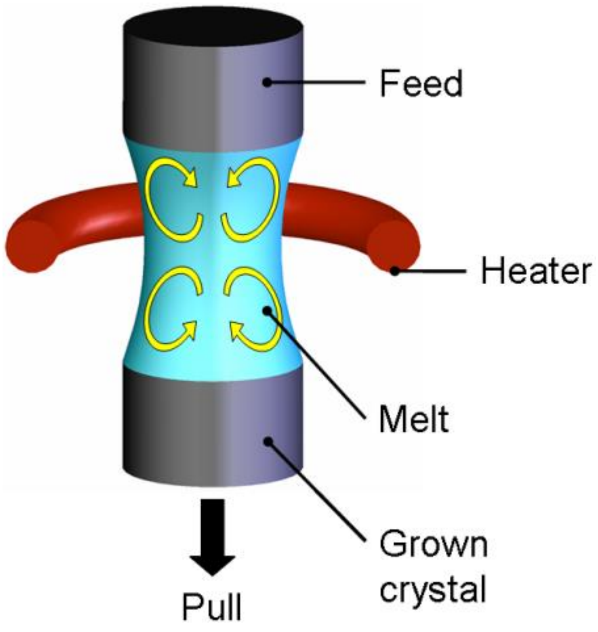
→Material processing





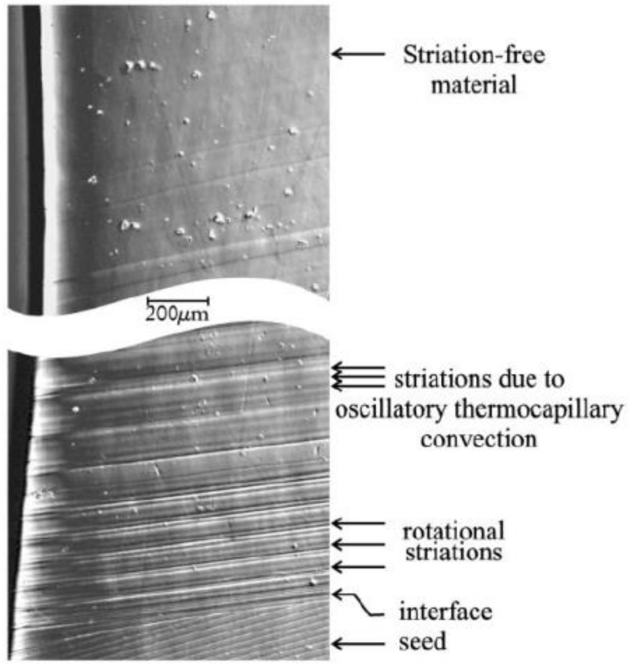
Production of semiconductor materials

Marangoni convection during the production of crystals such as for semiconductor and oxide material negatively affect the quality of the crystals.



Floating zone method

Grown crystal of GaSb both in microgravity and on earth

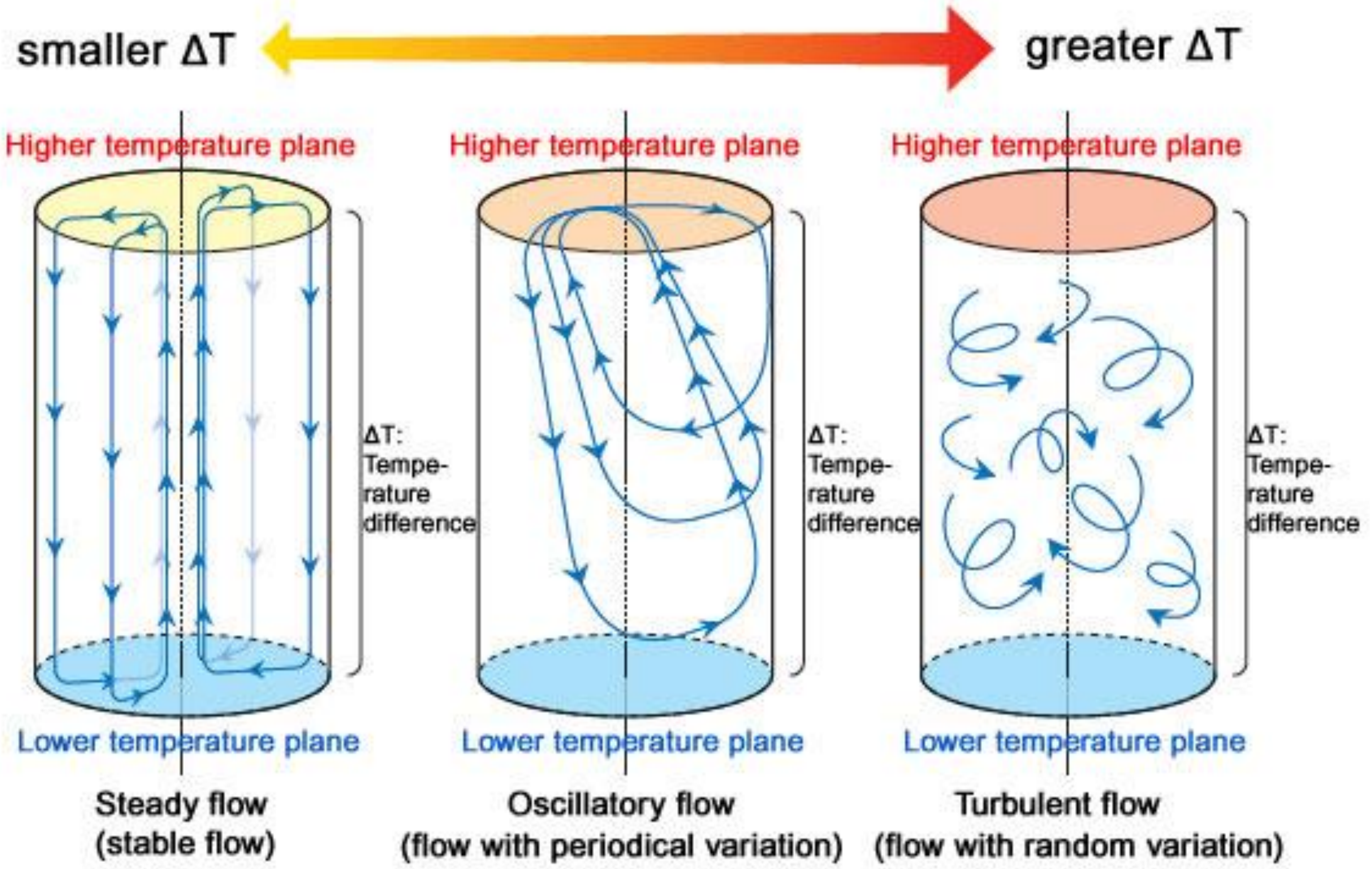


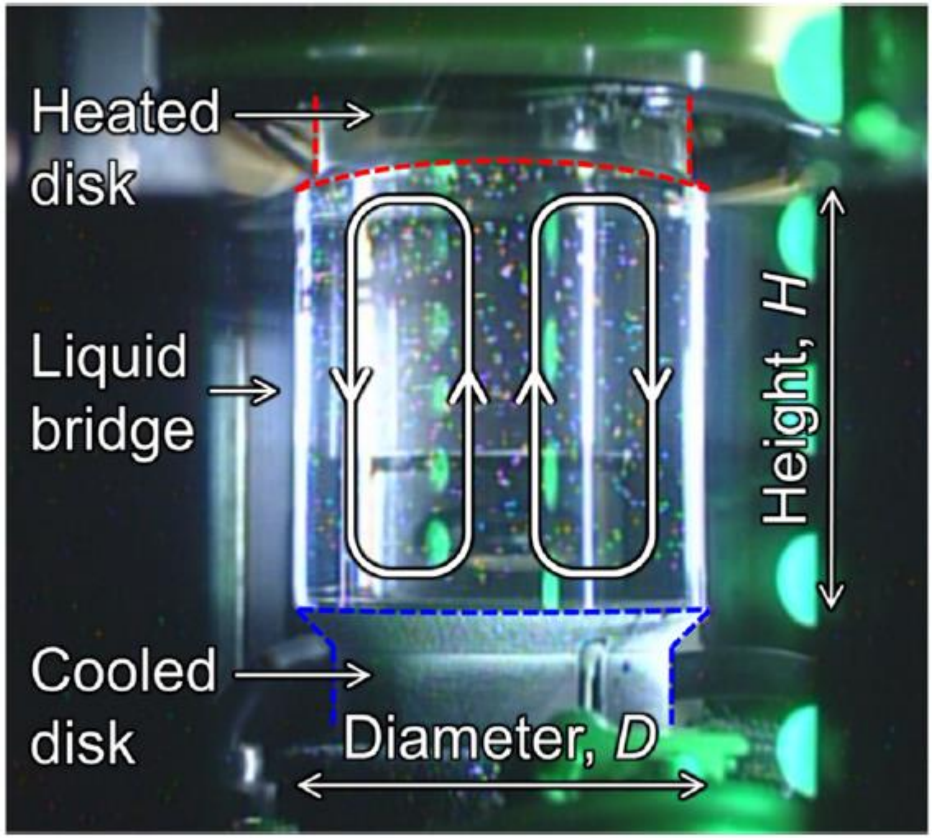
Cröll et al., *Journal of Crystal Growth* (1998)

Striations in the crystal due to oscillatory Marangoni convection

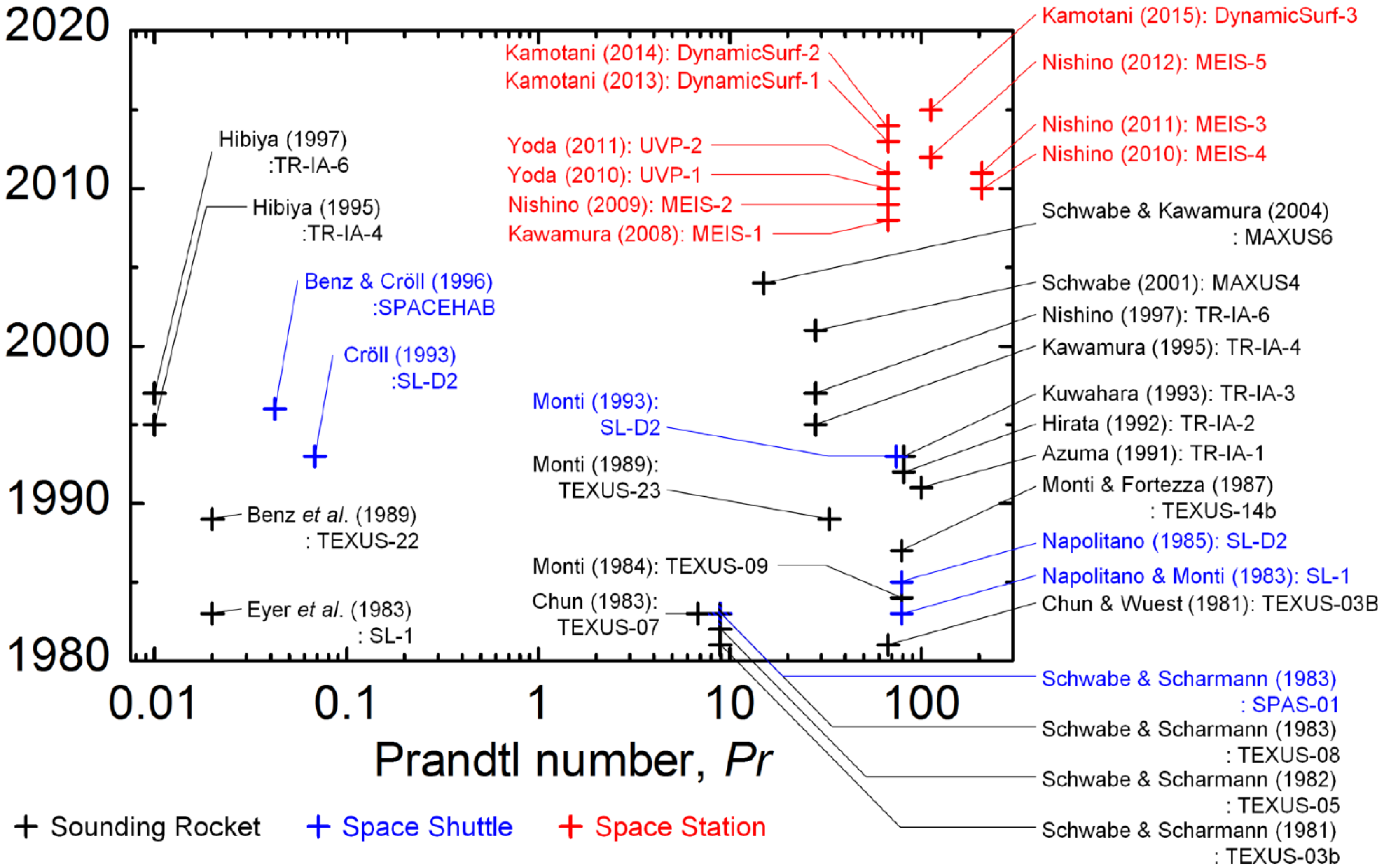
Flow Transition

Flow Transition from Steady to Oscillatory, Turbulence





T. Yano et al., Microgravity Science and Technology (2018)



T. Yano et al., Int. J. Microgravity Sci. Appl. (2018)

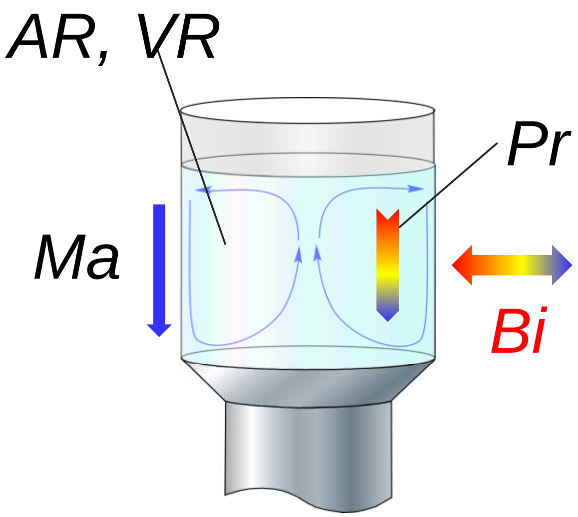
Marangoni number $Ma = \dfrac{|\sigma_T| \Delta T H}{\mu \alpha}$

Prandtl number $Pr = \dfrac{\nu}{\alpha}$

Aspect ratio $AR = H/D$

Volume ratio $VR = V/V_0$

Biot number $Bi = \dfrac{hH}{\lambda_l}$

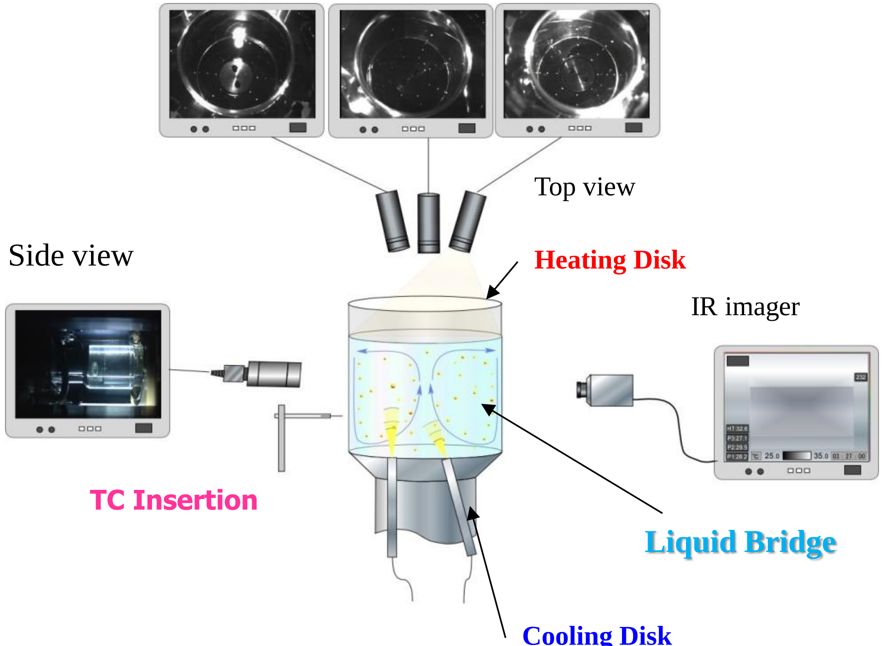


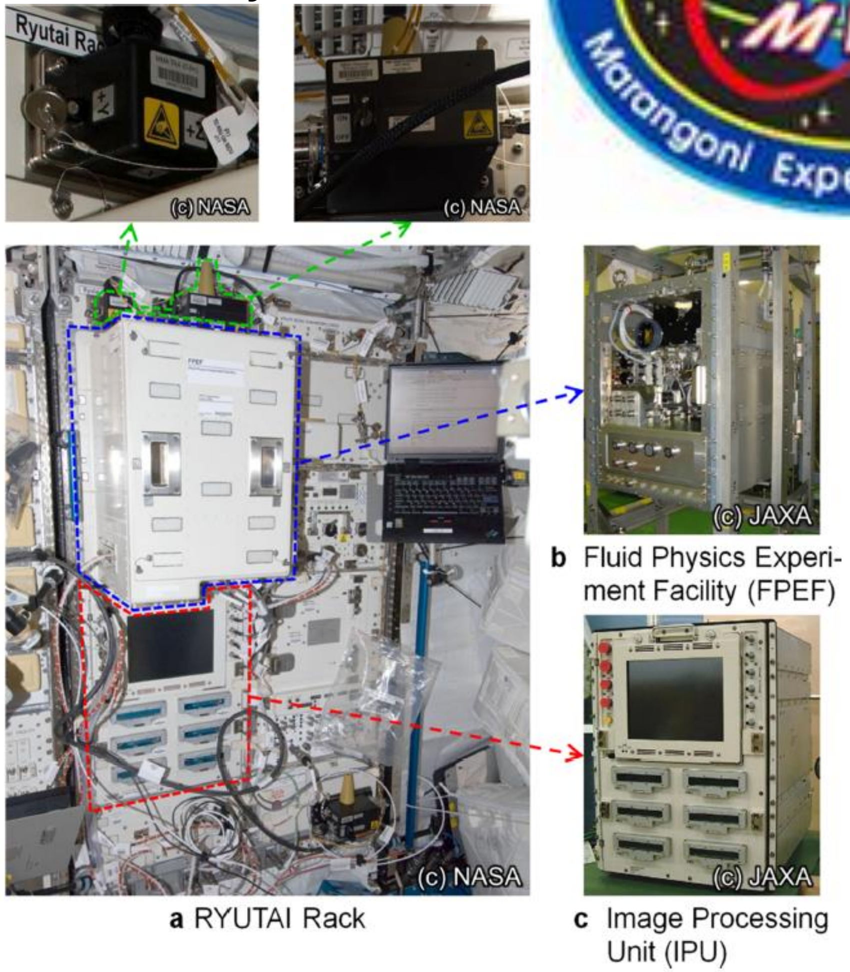
The history of microgravity experiments on Marangoni convection in liquid bridges.

Marangoni convection Experiment in ISS
MEIS Marangoni Experiment In Space

Tokyo University of Science, JAXA, Yokohama National University, JAMSS, JSF, IHI Aerospace

Liquid Bridge size
Diameter: 10, 30, 50 mm、 Height: up to 62.5 mm
Experiment Sample
Silicone Oil (viscosity; 5, 10, 20 cSt)
Pr = 67, 112, 207





T. Yano et al., Microgravity Science and Technology (2018)

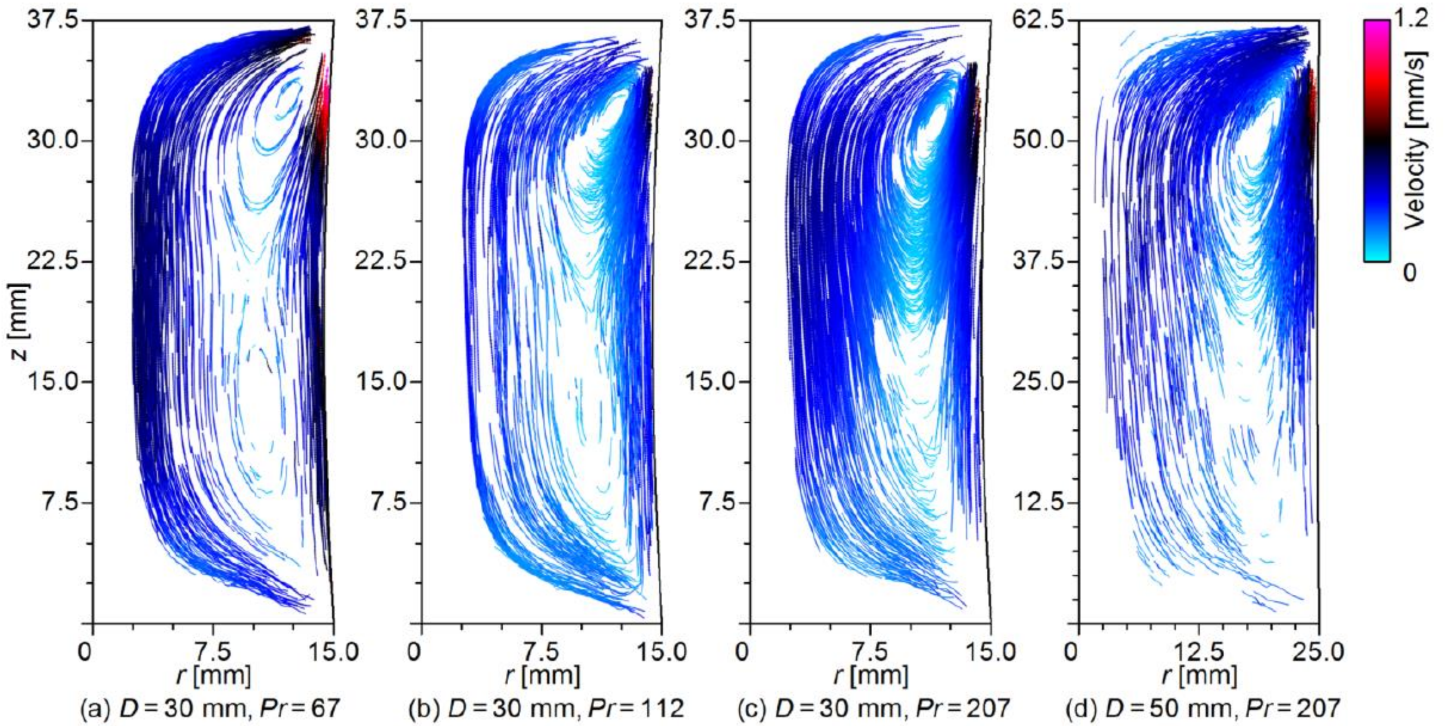
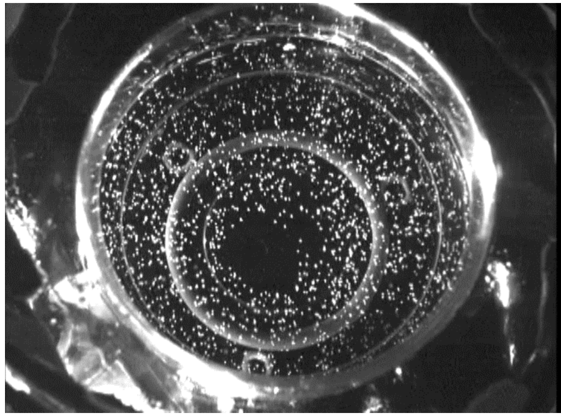
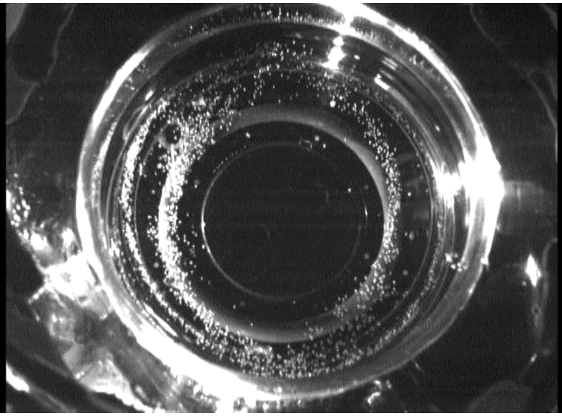
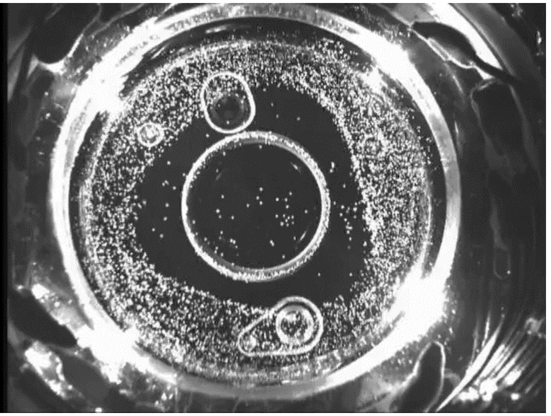


Fig. 8 Particle trajectories obtained by 3-D PTV for A = 1.25: (a) *MEIS-2*, (b) *DS-3*, (c) *MEIS-3*, and (d) *MEIS-4*. The experimental conditions are listed in **Table 4**.

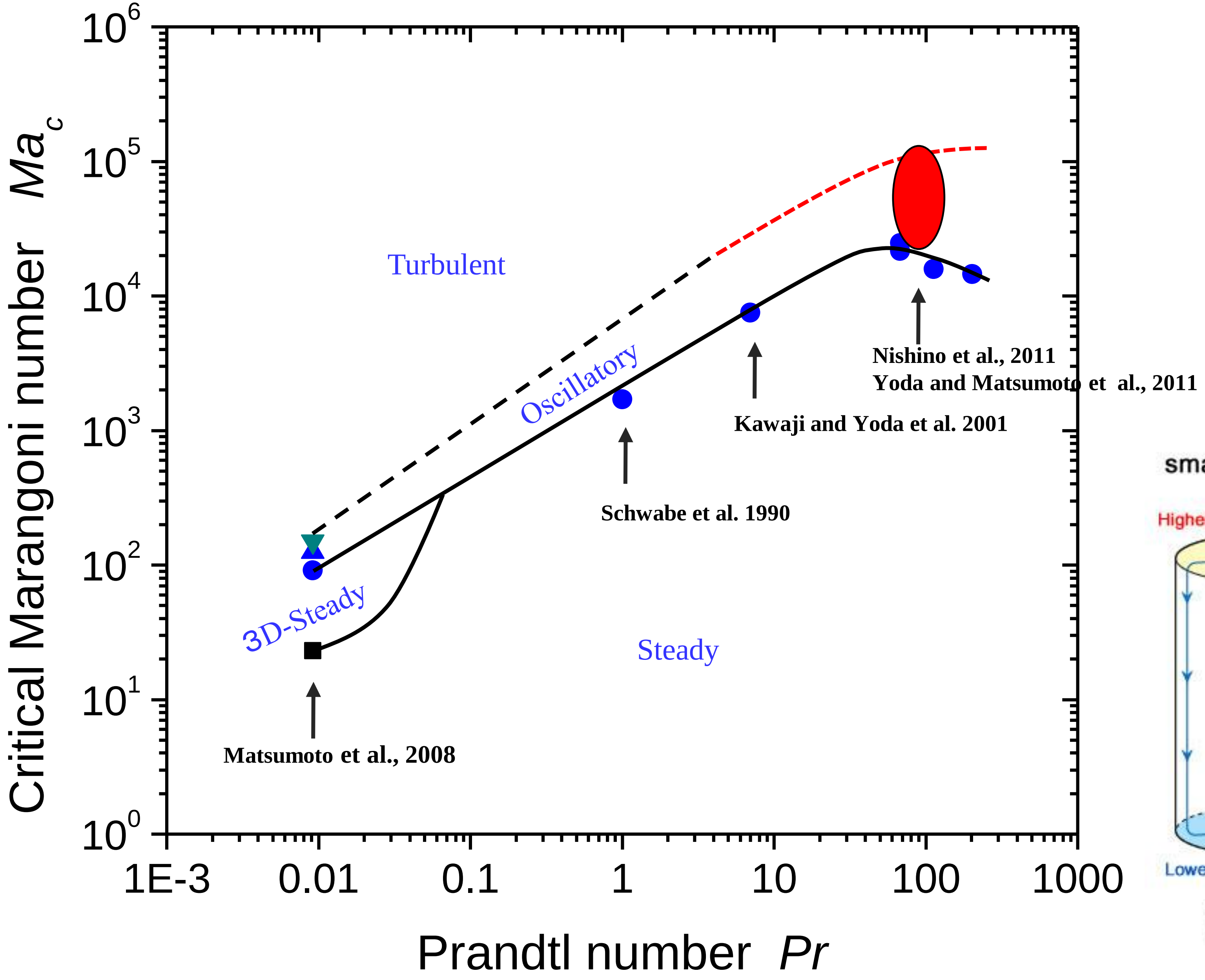
T. Yano et al., Int. J. Microgravity Sci. Appl. (2018)





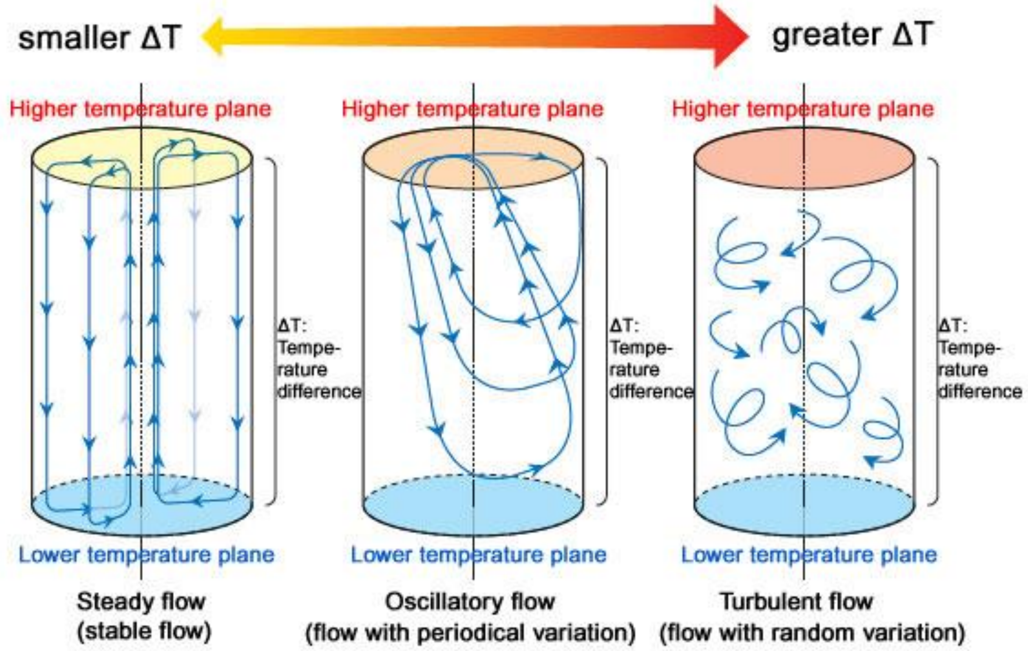


Estimated transition diagram



Marangoni number $$Ma = \frac{|\sigma_T| \Delta T H}{\mu \alpha}$$

Prandtl number $$Pr = \frac{\nu}{\alpha}$$



Concluding Remarks

- As the fluid dynamics under microgravity, following three examples were introduced.

  - ✓ **Liquid in container**
  - ✓ **Flow boiling and two-phase flow, ISS experiments**
  - ✓ **Marangoni convection, ISS experiments**

- There are following subjects which I could not present today

  Complex fluids, Interfacial Phenomena, Capillary Flow Phenomena,
  Colloids and Suspensions, Liquid Crystals (Structure and Dynamic Studies),
  Foams, Granular Materials,
  Magnetorheological Fluids, Polymer Fluids,
  Thermal and fluid dynamics related to propulsion system in future spacecraft